

OUTER PLANET SATELLITE STUDIES

Department of Astronomy, University of Texas at Austin

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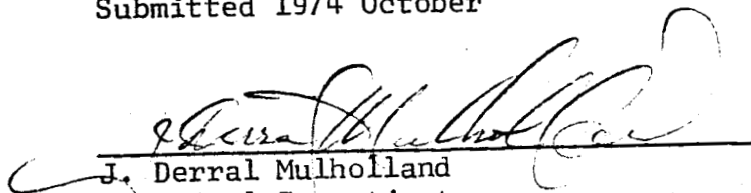
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NASA Scientific and Technical Information Facility
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Dear Sirs:

Enclosed please find three copies of the semi-annual status
report required by the terms of grant NGR 44-012-282.

Yours truly,


J. Derral Mulholland
Principal Investigator

Enclosures (3)

JDM/no

I. Research Summary

Observational program: Extensive coverage of the Uranus and Neptune systems, as well as at least three exposures of each of the satellites 4, 6-12, was obtained in the course of four observing runs on the Otto Struve 2.1 m reflector and one run on the 75 cm reflector of the McDonald Observatory. Arlot participated in the 1974 USNO observations of Galilean satellites and prepared predictions for the occultations of the Saturnian system.

Date reduction: At Austin, the application of the Skylab PDS microdensitometer to the measurement of astrometric plates has proven immensely successful in a series of quantitative tests. It is now being used to reduce the plates taken at McDonald. At the U.S. Naval Observatory, the SAMM has been used to reduce all of the 1968 and 1973 observations of the Galilean satellites taken by D. Pascu.

Instrumentation: Preparations are underway to manufacture nichrome spot filters with the UT Astronomy Department. A new double-slide system has been installed in the Cassegrain camera to improve image measurability. The possibility of constructing an automatic guiding system is under study.

Theoretical studies: The program to develop the disturbing function for the pairs of resonant (Saturnian) satellites is complete, as is a program to evaluate the final series for coordinates and partial derivatives. The elimination of the non-resonant terms from the Hamiltonian, for the case Enceladus-Dione, is now underway.

II. Personnel working on this grant during report period

Dr. J. Derral Mulholland	(Principal Investigator, not charged)
Dr. William H. Jefferys III	(Co-investigator, 1/3 time)
Dr. Peter J. Shelus	(Co-investigator, 1/4 time, not charged)

Dr. David W. Dunham	(Co-investigator, not charged)
Miss Lynne R. Ries	(Graduate student, 1/2 time)
Mr. Richard I. Abbot	(Graduate student, 1/4 time)
Mr. Jean-Eudes Arlot	(Consultant, full time)

III. Financial Status

During the report period, the budgeted funds were spent at somewhat in excess of a linear annual rate, as anticipated in the last report. Nonetheless, there was a significant carryover of funds into the next period, due to the slowness of early grant activities necessitated by mid-semester startup last November. We are pursuing an expanded observing schedule as a result of this situation.

IV. Observational Program

The observing program at McDonald Observatory is now well established. During the report period, four dark-Moon runs of four days each were scheduled on the Otto Struve 2.1 m telescope and one run of five days on the 76 cm reflector. All 21 days yielded successful observations, which is a remarkable record. Extensive coverage was obtained on the systems of Uranus (31 plates on 16 days over 2 1/2 months) and Neptune (40 plates on 20 days over 3 months). All of the middle and outer satellites of Jupiter were observed also, but not so heavily, because of their relatively small mean motions. The range extends from 3 observations over one month (XI and XII) to 7 observations over 3 months (VI). Observers included Abbot, Jefferys and Shelus. Table I summarizes the observations.

The Galilean satellites are not observed at McDonald, under an agreed division of responsibilities amongst the groups active in the coordinated satellite effort. However, Arlot assisted D. Pascu (USNO)

in his observations of those objects with the 53 cm (26") refractor of the Naval Observatory, Washington.

An unexpected conjunction of interests between two separate research projects arose during the past winter, when there were a series of lunar occultations of Saturn. High-precision observations of these events are capable of giving information on both the positions and diameters of the satellites. Dunham, currently funded under a grant for lunar studies, computed predictions of the satellite events based on data supplied by K. Aksnes (SAO) and distributed them to observers. Some visual observations were obtained in Europe on 1974 March 2-3, while photoelectric measures of the 1974 March 30 occultations of five satellites were obtained at Mauna Kea by a Cornell University team. Dunham is participating in the analysis of these data.

During the next period, two observing runs (September and January) are envisioned at McDonald for the 2.1 m telescope, as well as an October run on the 2.7 m reflector, the first such use of this instrument. A high priority is to be given to confirmation of the discovery of Jupiter XIII.

V. Data Reduction

Through the courtesy of Drs. K. Henize, J. D. Wray and, G. F. Benedict the NASA-SKYLAB PDS microdensitometer system at the University of Texas at Austin has been made available for our astrometric measures. This instrument is part of the reduction system for SKYLAB experiment SC19 and is only available for our programs on a limited basis. Since images are digitally directed, it is possible to make use of all positional information contained in those images to produce positions

Table 1: Summary of McDonald Satellite Observations

<u>Object</u>	<u>Date</u>	<u>Telescope</u>	<u>Plates</u>	<u>Exposures</u>	<u>Observer</u> *
Jupiter 6	1974 May 18	0.76 m	1	1	S
	Jun 28	2.1	1	4	S
	Jul 24		1	3	S
	25		1	1	S
	Aug 13		2	2	S
	15		1	1	S
Jupiter 7	Jun 25		1	1	S
	Jul 25		1	1	A
	Aug 15		1	1	S
Jupiter 8	Jun 26		1	1	A
	Jul 25		1	1	S
	Aug 13		1	1	S
	15		1	1	S
	16		1	1	JA
Jupiter 9	Jun 27		1	1	A
	Jul 24		1	1	S
	Aug 13		1	1	S
	15		1	1	S
Jupiter 10	Jun 28		1	1	A
	Jul 24		1	1	A
	Aug 14		1	1	S
	16		1	1	S
Jupiter 11	Jul 23		1	1	A
	26		1	1	S
	Aug 14		1	1	S
	Jul 23		1	1	S
Jupiter 12	26		1	1	A
	Aug 14		1	1	S
	Jul 23		1	1	S
Uranus system	May 14		3	13	S
	15		3	12	S
	16		3	12	S
	17		3	12	S

Table 1 (Continued)

Uranus system	May 18	0.76	1	4	J
	20		2	8	S,J
	21		1	4	J
	22		3	12	J
	Jun 25	2.1	2	5	A,S
	26		2	5	S,A
	27		1	4	S
	28		3	6	S,A
	Jul 23		1	4	A
	24		1	4	S
	25		1	2	A
	26		1	1	S
Neptune system	May 14		1	4	S
	15		2	8	S
	16		2	8	S
	17		1	4	S
	18	0.76	2	8	S,J
	19		2	8	J
	20		2	8	J
	21		2	8	J
	22		3	12	J
	Jun 25	2.1	3	6	S,A
	26		3	12	A,S
	27		2	6	A
	28		4	13	S,A
	Jul 23		2	8	S,A
	24		1	4	A
	25		2	8	S,A
	26		2	8	A,S
	Aug 13		2	8	S
	15*		1	3	JA
	16		1	3	S

* Observers: A = R. I. Abbot, J = W. H. Jefferys, JA = J. Africano
S = P. J. Shelus

of the highest quality. A preliminary analysis of the 1σ scatter in the position of a single star determined from a single plate has been made by W. F. Van Altena giving a tentative value of $\sigma = 1.0 \mu$. Further advantages of this system include the elimination of personal equation and the ability to accurately measure images which are fainter than those which can be measured by hand centering techniques. On satellite plates where images are extremely close to highly overexposed primaries, the subtraction of modelled background density has proven to be significant in the acquisition of more accurate positions. Finally a typical satellite plate with some 30-40 reference stars and 1-10 satellites can be scanned by the PDS system in less than 30 minutes; the corresponding time for hand measures is several hours.

Using the PSS microdensitometer system and employing the necessary software to produce positions from digitally scanned information the standard deviations in right ascension and declination of the fit in determining the satellite plate reference stars from SAO catalog stars on the National Geographic-Palomar Sky Survey glass copies have been in a range $0''.4-0''.5$, which is the approximate accuracy of a single SAO position. A limited field of SAO stars in a box approximately 2° on a side centered on the satellite field is used. The standard deviations in right ascension and declination in determining absolute satellite positions from the "bootstrap" reference star system have been in the range $0''.2-0''.4$. These values only apply to the first measured set of images on a satellite plate, since most plates contain four to six exposures each, combining the measures to form a normal point plate will statistically reduce these figures. The total uncertainty of the

absolute positions of satellites will be a weighted R.M.S. sum of the two uncertainties mentioned above. It is anticipated that the availability of more accurate catalogs of reference stars shall allow more accurate absolute positions to be obtained from our measures. For the present, since our measures are more accurate than the reference frame to which they are compared, when the greatest accuracy is desired, inter-satellary distances can probably be given with far greater accuracy than can be absolute positions.

Since the use of the PDS microdensitometer is limited, progress on plate measures has not been as fast as desired. Through August we have satisfactorily scanned all of Mulholland's 2.1 meter observations of Saturn during the 1972 December opposition. We are presently in the process of scanning the 76 cm observations for that opposition and anticipate to be completed with that set by late fall. At that time the result of those measures will be presented in suitable astronomical literature.

Using the SAMM, at the USNO, Arlot measured and reduced all of Pascu's 24 plates (72 exposures) taken of the Galilean satellite with the USNO 66 cm telescope in 1973. Four of Pascu's 1968 plates were remeasured and a partial rereduction was performed on the total of 28 plates (95 exposures).

VI. Instrumentation

It has been decided to fabricate the nichrome spot filters with equipment and personnel here at the University of Texas at Austin. This should allow us use of such filters at considerable savings over commercial or other means of obtaining these items.

Since studies on the faint outer satellites of Jupiter require quite long exposure times at the telescope, in the interest of ease and accuracy, we have been studying the possibility of adding automatic guiding capability to our camera. We are presently examining an image dissecting instrument which would be used with a Nova mini-computer interface. Such would allow suitable offsets to be input to the system to allow the photographic plate to move with the satellite which is moving with respect to the stellar background (and, of course, with respect to the guide star also). It is hoped that partial support will be obtained from McDonald Observatory with the remainder of funds required coming from the savings realized in our own fabrication of spot filters.

Presently, using hand guiding techniques, when obtaining exposures of the faint outer satellites of Jupiter in order to record faint satellite images one moves the photographic plate with respect to the stellar background to mimic the satellites' motion. Of necessity one thereby obtains exposures with a point satellite image and reference star trails. Since such star trails are difficult to measure accurately we are attempting to devise an observing technique to eliminate star trails. The following modification to our plate holders have been made, but have not, as yet, been tested. A double dark slide system is employed. One slide is a normal dark slide; the other is identical to the first except that a small diameter hole is placed in the center of the slide. An exposure begins with the removal of both dark slides. After exposing the full plate for a time (3 to 5 minutes) sufficient to record a suitable reference frame upon the plate the dark slide with

the hole is replaced. Thus during the maximum part of the exposure only the central part of the plate is being exposed. Near the end of the exposure the second dark slide is again removed and the reference star frame is again impressed on the field. Of course, since the photographic plate is moved with respect to the star reference frame throughout the exposure the second "full-plate exposure" displaces the second reference star frame with respect to the first. The end result is a plate with two sets of reference stars and one satellite image. Since all images are points instead of trails, measures can be made far more accurately. The identical system can produce similar results if and when we employ automatic guiding techniques.

VII. Theory of Encyladus-Dione

Since starting in February, progress on the orbits of resonant satellite pairs has been satisfactory. The biggest job is to develop the "disturbing function," which contains the essential dynamics, into a multiple Fourier series in its arguments. A program has been developed in the TRIGMAN language to accomplish this. This program allows for variable precision in making the development, so that the desired precision can be selected at will. For test purposes, we are working exclusively with the system Enceladus-Dione. Ultimately we intend to use the same programs on the other two pairs of satellites as well (Mimas-Tethys and Titan-Hyperion).

A test program has been written to take the resulting series development and evaluate it and its derivatives at selected points, and compare these values with the exact formulae. This program has

been used to verify the series expansions, and is retained as a test program for the rest of the project.

Finally, routines have been programmed for the calculation of the partial derivatives of an arbitrary expression with respect to any of a set of canonical (Delaunay) variables. These routines will be required for the next stage and for the production of the final results. A paper on the methods used to expand the disturbing function is in preparation.

An incidental result of the activities has been to make several expansions of the TRIGMAN language, specifically to allow subscripted variables in the series expansions and more expeditious evaluation of series. A by-product of the improvements to TRIGMAN has been some research into the fastest ways to evaluate series in FORTRAN programs (Shelus & Jefferys, see Section IX). Finally, a bug in the TRIGMAN output package has been located and removed as a result of our activities this year.

We are currently embarked on the next step, the elimination of all terms from the Hamiltonian except for the resonant terms. This should not take too long. After that, it will be necessary to study the resonant Hamiltonian in order to determine the best way to handle it. The final stage will be to produce FORTRAN decks for the direct evaluation of the perturbations and their derivatives. These will be executable on any machine supporting FORTRAN IV, and not only the CDC 6600.

VIII. Theory of Galilean Satellites

Pascu's observations of the Galilean satellites were compared

with computed positions from Sampson's theory, as provided by the Bureau des Longitudes. The results (Arlot, see section IX) included solutions for errors in both the theory and the observations, and they indicate time-variant longitude errors in the theories of all four objects.

IX. Publications

Arlot, J. E. "A Comparison of Some Observations of the Galilean Satellites With the Theory" Presented at IAU/COSPAR Symposium on Natural Satellites, Ithaca, 1974 August.

Shelus, P. J., Abbot, R. I., and Mulholland, J. D. "Observations of Outer Planet Satellites" Presented at IAU/COSPAR Symposium on Natural Satellites, Ithaca, 1974 August.

Shelus, P. J., and Jefferys, W. H. "A Note on an Attempt at More Efficient Poisson Series Evaluation," Celestial Mechanics, in press.